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Chu

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(54) **METHOD AND APPARATUS FOR TRANSMITTING WIRELESS NETWORK OPERATIONAL INFORMATION**

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H04L 29/06	(2006.01)
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CPC ***H04W 72/046*** (2013.01); ***H04B 7/0413*** (2013.01); ***H04L 1/0606*** (2013.01); ***H04L 1/0612*** (2013.01); *H04W 84/12* (2013.01)

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CPC ... H04L 5/0003; H04L 5/0058; H04L 47/365; H04L 47/38; H04L 47/58; H04L 69/166; H04W 28/065; H04W 80/06; H04W 84/12; H04B 7/0413
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,710,939 B2 *	5/2010	Shao	....	H04W 52/0225 370/311
8,144,647 B2	3/2012	Nabar et al.		

(Continued)

FOREIGN PATENT DOCUMENTS

WO WO-2012/122119 A1 9/2012

OTHER PUBLICATIONS

IEEE Std 802.11ac/D7.0 "Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz," *The Institute of Electrical and Electronics Engineers, Inc.*, pp. 1-456 (Sep. 2013).

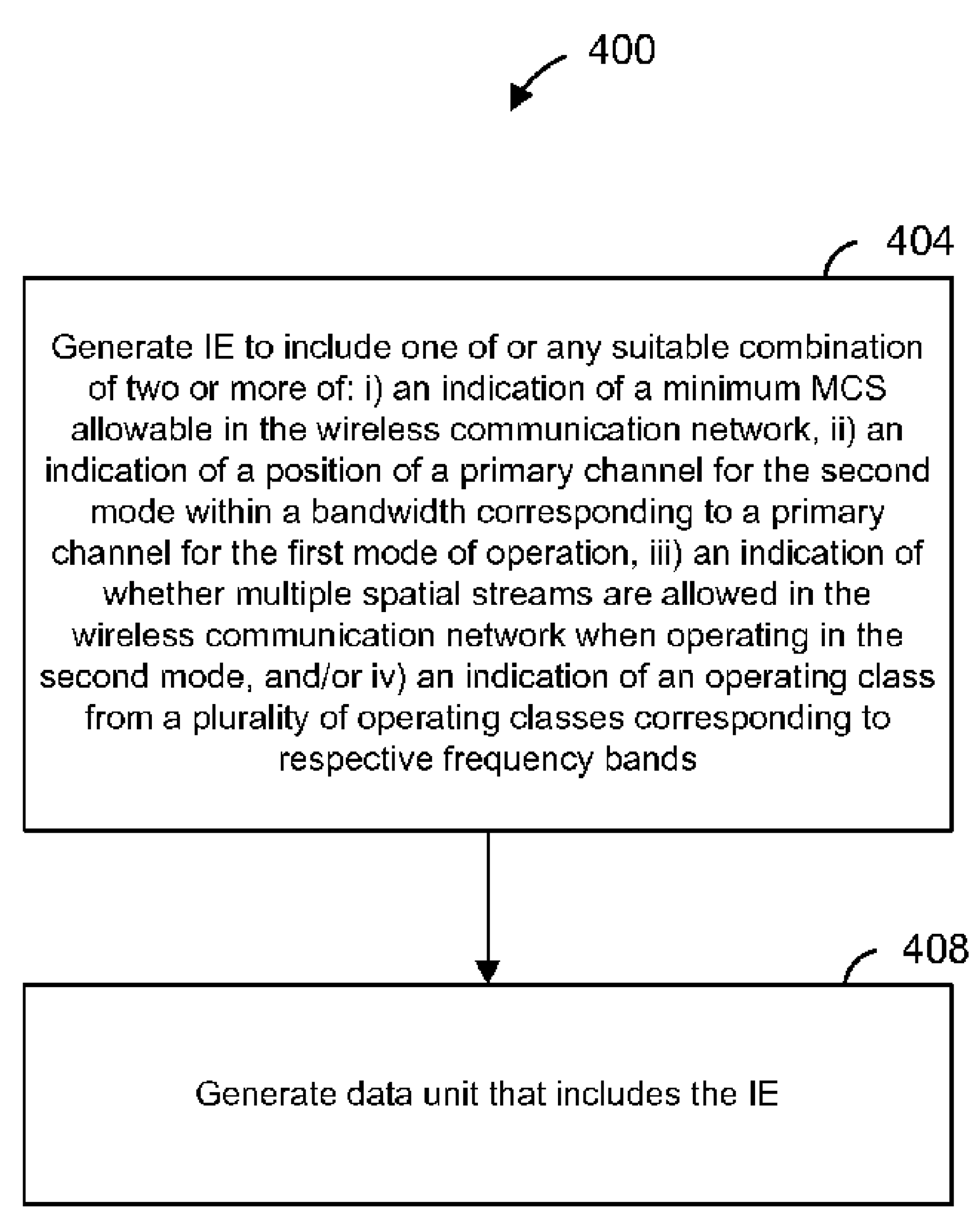
(Continued)

Primary Examiner — Alpus H Hsu

(57) **ABSTRACT**

A communication device generates an informational element (IE) to include an indication of a minimum modulation and coding scheme (MCS) allowable in a wireless communication network. The minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network. The indication of the minimum MCS also indicates use of any MCSs below the minimum MCS in the ordered set of MCSs is not allowed in the wireless communication network. The communication device generates a data unit that includes the IE.

18 Claims, 7 Drawing Sheets



(51) **Int. Cl.**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

8,170,606	B2 *	5/2012	Dorsey	H04B 1/036 370/311
8,244,296	B2 *	8/2012	Dorsey	H04B 1/036 370/311
8,289,952	B2 *	10/2012	Larsson	H04L 1/0003 370/328
8,346,299	B2 *	1/2013	Dorsey	H04B 1/036 370/311
8,554,261	B2 *	10/2013	Niu	H04L 1/0003 455/25
8,611,288	B1 *	12/2013	Zhang	H04B 7/0619 370/235
8,619,814	B2 *	12/2013	Seok	H04W 80/02 370/329
8,665,949	B1 *	3/2014	Zhang	H04L 27/2627 370/535
8,699,340	B2 *	4/2014	Fantaye	H04L 1/0003 370/232
8,761,108	B2 *	6/2014	Ren	H04L 1/0003 370/329
8,767,854	B2 *	7/2014	Zheng	H04L 27/2626 370/203
8,787,341	B2 *	7/2014	Sohn	H04L 1/0025 370/241
8,885,495	B1 *	11/2014	Liu	H04B 7/0617 370/252
2006/0187964	A1 *	8/2006	Li	H04W 74/002 370/474
2009/0196163	A1	8/2009	Du	
2010/0260114	A1 *	10/2010	Vermani	H04L 1/1854 370/329
2010/0271963	A1 *	10/2010	Koorapaty	H04L 1/0003 370/252
2011/0194419	A1 *	8/2011	Lee	H04H 20/423 370/242
2011/0261783	A1 *	10/2011	Mo	H04W 28/06 370/330
2012/0195391	A1	8/2012	Zhang et al.	
2012/0201316	A1	8/2012	Zhang et al.	
2012/0294294	A1	11/2012	Zhang	
2012/0300874	A1	11/2012	Zhang	
2013/0010896	A1 *	1/2013	Jiao	H04B 7/0417 375/296
2013/0202001	A1	8/2013	Zhang	
2013/0286961	A1 *	10/2013	Vermani	H04L 1/0003 370/329
2014/0269659	A1 *	9/2014	Wentink	H04W 28/065 370/338
2016/0226623	A1 *	8/2016	Froberg Olsson	H04L 1/0023

OTHER PUBLICATIONS

IEEE Std 802.11™ 2012 (Revision of IEEE Std 802.11-2007) IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, *The Institute of Electrical and Electronics Engineers, Inc*., pp. Jan. 2695 (Mar. 29, 2012).

IEEE STD 802.11af/D1.05 "Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: TV White Spaces Operation," *The Institute of Electrical and Electronics Engineers, Inc*., pp. 1-123 (Nov. 2011).

Lee et al., "TGaf PHY proposal," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-12/0809r5, pp. 1-43, Jul. 10, 2012.

IEEE Std 802.11ah™/D1.0 "Draft Standard for Information Technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 6: Sub 1 GHz License Exempt Operation," *The Institute of Electrical and Electronics Engineers*, Inc., pp. 1-394 (Oct. 2013).

Yu et al., "Coverage extension for IEEE802.11ah," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/0035r1, pp. 1-10 (Jan. 2011).

Taghavi et al., "Introductory Submission for TGah", doc. No. IEEE 802.11-11/0062r0, *Institute for Electrical and Electronics Engineers*, pp. 1-5 (Jan. 14, 2011).

de Vegt, "Potential Compromise for 802.11ah Use Case Document", Institute of Electrical and Electronics Engineers, doc. No. IEEE 802.11-11/0457r0, pp. 1-27 (Mar. 2011).

Zhang et al., "11ah Data Transmission Flow," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1484r1, pp. 1-15 (Nov. 2011).

Park, "Proposed Specification Framework for TGah", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1137r6, pp. 1-13 (Mar. 2012).

Park, "Proposed Specification Framework for TGah D9.x", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-yy/xxxxr0, pp. 1-30 (Jul. 2012).

Vermani, et al. "Preamble Format for 1 MHz," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1482r2, pp. 1-30 (Nov. 2011).

Zhang et al., "1 MHz Waveform in Wider BW", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-12/0309r1, pp. 1-10 (Mar. 2012).

Vermani, et al. "Spec Framework Text for PHY Numerology," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/13111-0, pp. 1-5 (Sep. 2011).

Park, "Proposed Specification Framework for TGah", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1137r11, pp. 1-36 (Sep. 2012).

Park, "Specification Framework for TGah," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1137r13, pp. 1-58 (Jan. 14, 2013).

Zhang et al., "Beamforming Feedback for Single Stream," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-12/1312r0, pp. 1-22 (Nov. 12, 2012).

Shao, "Channel Selection for 802.11ah," doc.: IEEE 802.11-12/0816r0, pp. 1-11 (Jul. 2012).

Park, "Proposed Specification Framework for TGah", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11--yy/xxxxr05, (Jan. 2012).

Gunnam, et al., "Multi-Rate Layered Decoder Architecture for Block LDPC Codes of the IEEE 802.11n Wireless Standard," IEEE International Symposium on Circuits and Systems, 2007 (ISCAS 2007), pp. 1645-1648 (2007).

IEEE Std 802.11a-1999 (Supplement to IEEE Std 802.11-1999) "Supplement to IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-Speed Physical Layer in the 5 GHZ Band," *The Institute of Electrical and Electronics Engineers, Inc*., pp. 1-91 (Sep. 1999).

IEEE Std 802.11ac/D2.0 "Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz," *The Institute of Electrical and Electronics Engineers, Inc*., pp. 1-359 (Jan. 2012).

IEEE Std 802.11b-1999/Cor 1-2001 (Corrigendum to IEEE Std 802.11b-1999) "IEEE Standard for Information technology—Tele-

(56) **References Cited**

OTHER PUBLICATIONS

communications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 2: Higher-speed Physical Layer (PHY) extension in the 2.4 GHz band-Corrigendum 1," The Institute of Electrical and Electronics Engineers, Inc., pp. 1-23 (Nov. 7, 2001).

IEEE Std 802.11g/D8.2, Apr. 2003 (Supplement to ANSI/IEEE Std 802.11, 1999 (Reaff 2003)) "Draft Supplement to Standard [for] Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Further Higher Data Rate Extension in the 2.4 GHz Band," *The Institute of Electrical and Electronics Engineers, Inc.*, pp. 1-69 (Apr. 2003).

* cited by examiner

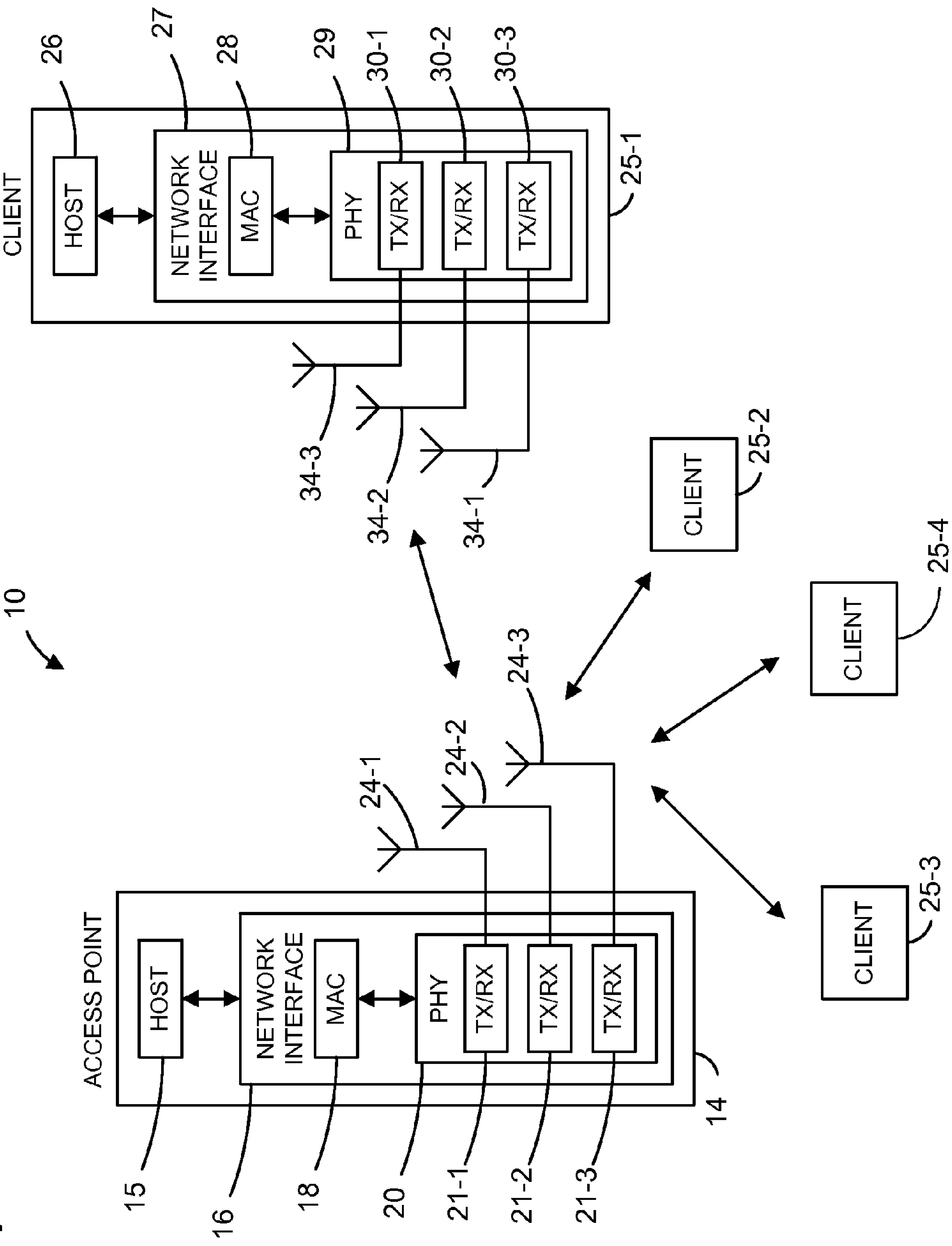

10
CLIENT
HOST
NETWORK INTERFACE
MAC
PHY
TX/RX
TX/RX
TX/RX
26
27
28
29
30-1
30-2
30-3
25-1
34-3
34-2
34-1
CLIENT
25-2
CLIENT
25-4
CLIENT
25-3
24-1
24-2
24-3
ACCESS POINT
HOST
NETWORK INTERFACE
MAC
PHY
TX/RX
TX/RX
TX/RX
14
15
16
18
20
21-1
21-2
21-3

FIG. 1

FIG. 2A

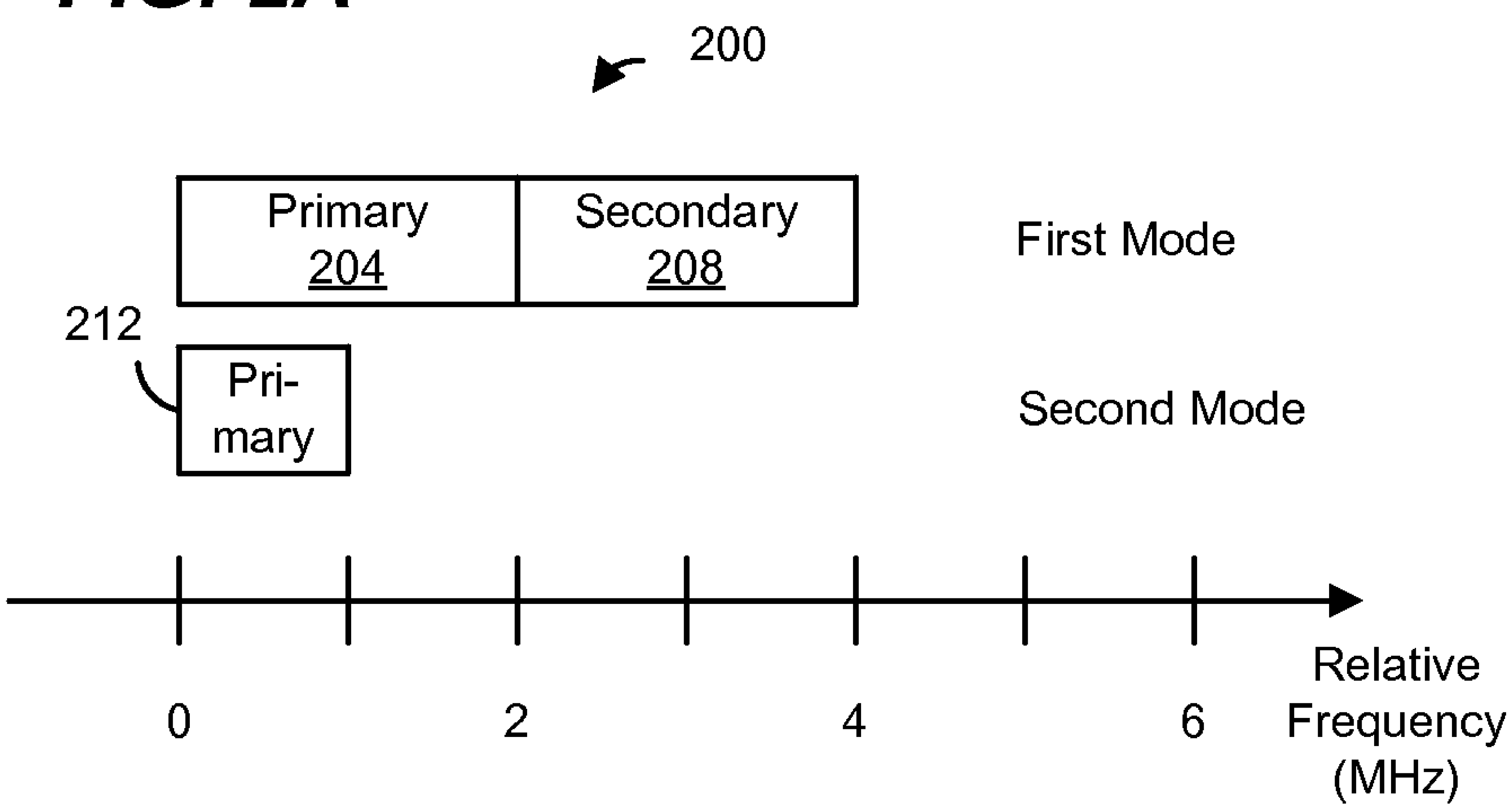

200
Primary
204
Secondary
208
First Mode
212
Pri-
mary
Second Mode
0
2
4
6
Relative
Frequency
(MHz)

FIG. 2B

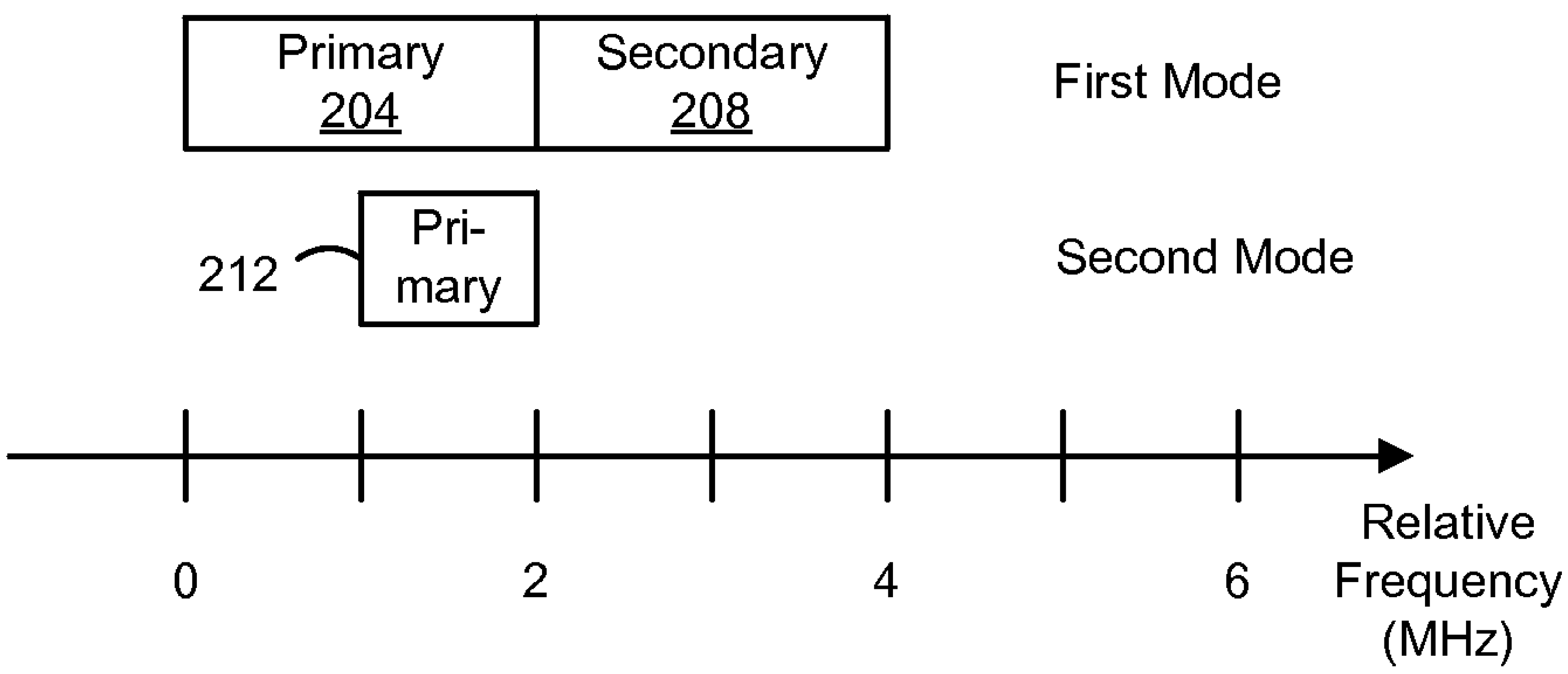

Primary
204
Secondary
208
First Mode
212
Pri-
mary
Second Mode
0
2
4
6
Relative
Frequency
(MHz)

FIG. 3A

300

	Element ID 304	Length 308	S1G Operational Information 312	Basic S1G-MCS and N_{SS} Set 316
Octets:	1	1	4	4

FIG. 3B

312

	Operating Channel and 1 MHz Restriction 320	Operating Class 324	Primary Channel Number 328
Octets:	1	2	1

FIG. 3C

340

Field	Description	Encoding
Operating Channel and 1 MHz Restriction 320	This field defines the BSS operating channel width (see 10.39.1 (Basic S1G BSS functionality)), primary channel position and 1MHz transmission restriction.	Bitmap of B0-B2 indicates the operating channel widths, 1/2/4/8/16MHz. B2, B1, B0 are set to 000 when the BSS operation Bandwidth is 1MHz, B2, B1, B0 are set to 001 when the BSS operation Bandwidth is 2MHz, B2, B1, B0 are set to 010 when the BSS operation Bandwidth is 4MHz, B2, B1, B0 are set to 011 when the BSS operation Bandwidth is 8MHz, B2, B1, B0 are set to 100 when the BSS operation Bandwidth is 16MHz, 101 to 111 of B2, B1, B0 are reserved. B3 bits indicates the location of 1MHz transmission in a BSS with >=2MHz operation channel width. This bit is reserved when the BSS Operation Channel is 1MHz -B3 is set to 0 to indicate a lower side of 2MHz primary channel. -B3 is set to 1 to indicate a upper side of 2MHz primary channel. Bitmap of B6-B4 indicates the position of 2MHz primary channel where B6,B5,B4=000 indicates the lowest 2MHz of the BSS operating channel and B6,B5,B4=111 indicates the highest 2Mhz of the BSS operating channel of 16MHz. These bits are reserved when the BSS Operation Channel is 1MHz. B7 being 1 means only a single spatial stream PPDU can be used at 1MHz channel width. B7 being 0 means that the 1MHz spatial stream can be same as other bandwidth.
Operating Class 324	This field defines the oprating class that the BSS is operating in	Operating Class encoding.
Primary Channel Number 328	Primary Channel Number field indicates the channel number of 2 MHz primary channel.	Primary Channel Number encoding.

FIG. 3D

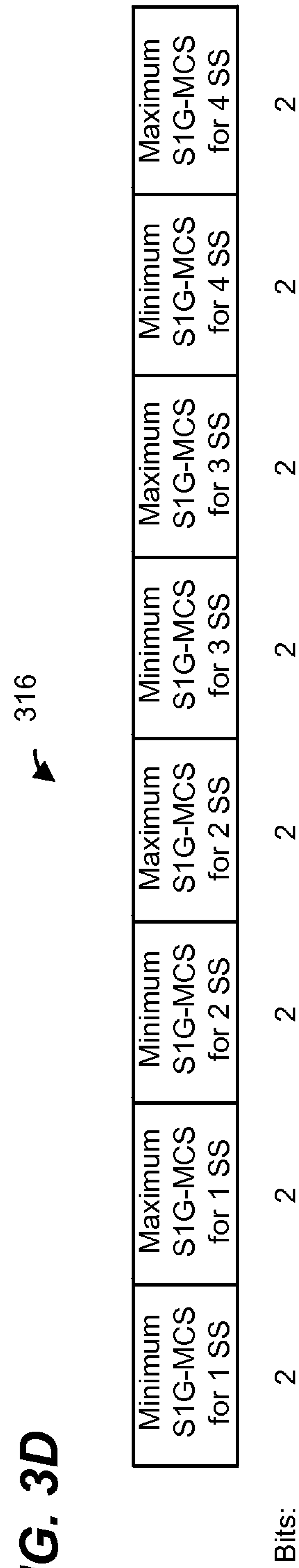

316
Minimum S1G-MCS for 1 SS
Maximum S1G-MCS for 1 SS
Minimum S1G-MCS for 2 SS
Maximum S1G-MCS for 2 SS
Minimum S1G-MCS for 3 SS
Maximum S1G-MCS for 3 SS
Minimum S1G-MCS for 4 SS
Maximum S1G-MCS for 4 SS
Bits: 2 2 2 2 2 2 2 2

FIG. 4

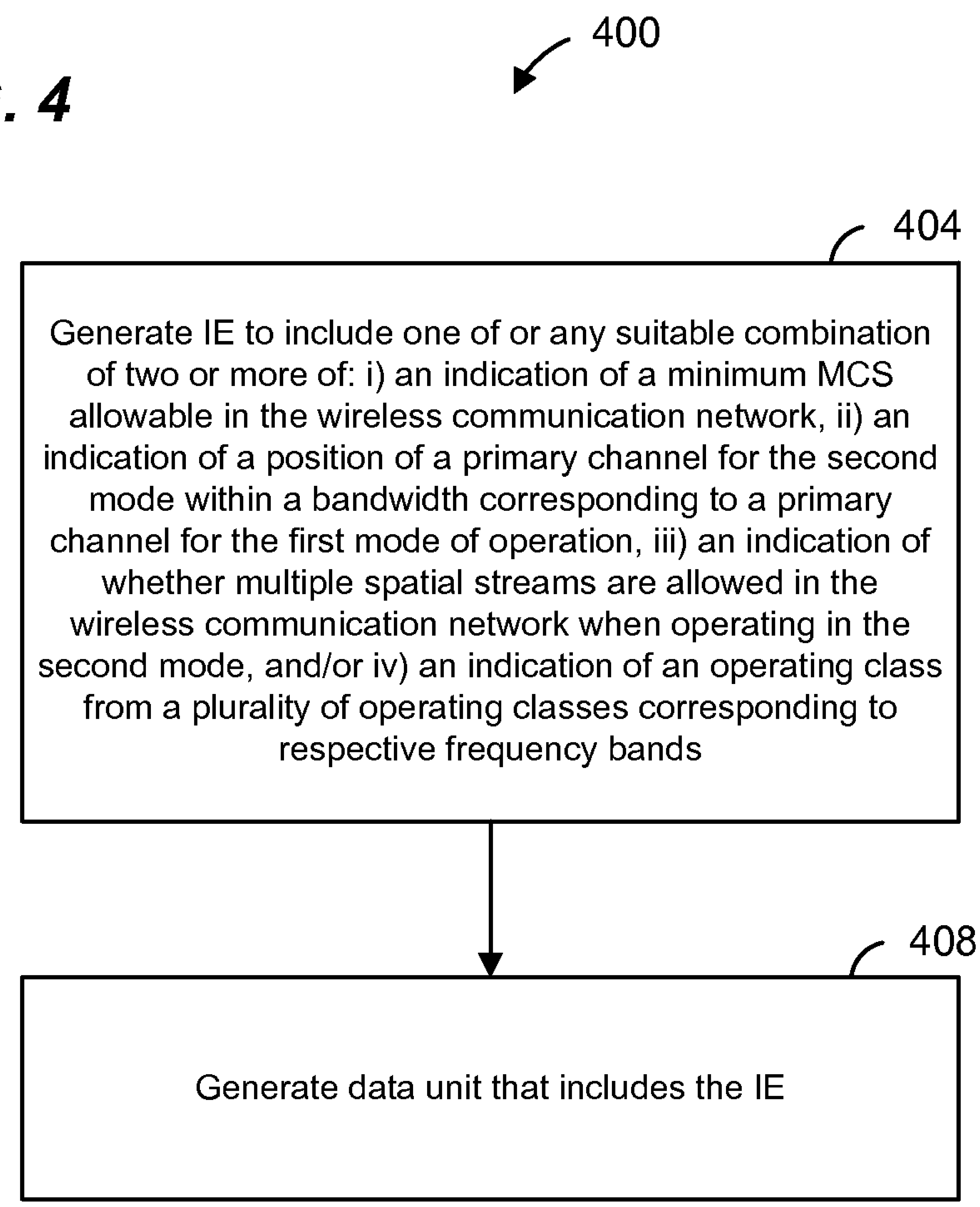

400
404
Generate IE to include one of or any suitable combination of two or more of: i) an indication of a minimum MCS allowable in the wireless communication network, ii) an indication of a position of a primary channel for the second mode within a bandwidth corresponding to a primary channel for the first mode of operation, iii) an indication of whether multiple spatial streams are allowed in the wireless communication network when operating in the second mode, and/or iv) an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands
408
Generate data unit that includes the IE

FIG. 5A

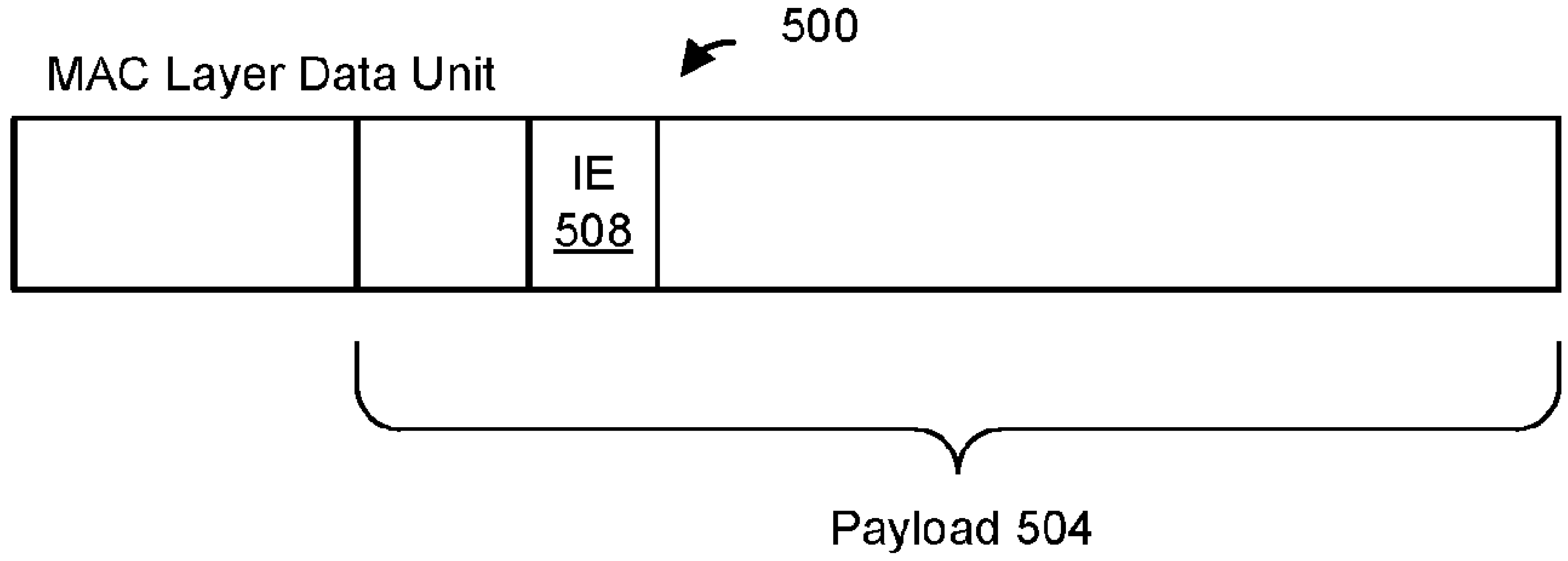
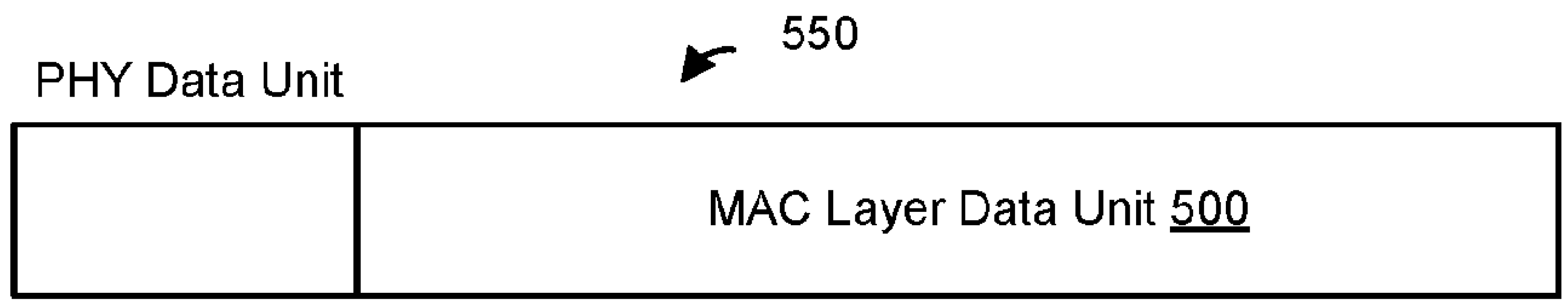

500
MAC Layer Data Unit
IE
508
Payload 504

FIG. 5B


550
PHY Data Unit
MAC Layer Data Unit 500

METHOD AND APPARATUS FOR TRANSMITTING WIRELESS NETWORK OPERATIONAL INFORMATION

CROSS-REFERENCE TO RELATED APPLICATION

This disclosure claims the benefit of U.S. Provisional Patent Application No. 61/920,979, filed Dec. 26, 2013, entitled "S1G Operation Element," which is hereby expressly incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to wireless communication networks, and describes embodiments in which an access point (AP) disseminates operational information in a wireless local area network (WLAN).

BACKGROUND

Wireless local area network (WLAN) technology has evolved rapidly over the past decade. Development of WLAN standards such as the Institute for Electrical and Electronics Engineers (IEEE) 802.11a, 802.11b, 802.11g, 802.11n, 802.11ac Standards has improved single-user peak data throughput. For example, the IEEE 802.11b Standard specifies a single-user peak throughput of 11 megabits per second (Mbps); the IEEE 802.11a and 802.11g Standards specify a single-user peak throughput of 54 Mbps; the IEEE 802.11n Standard specifies a single-user peak throughput of 600 Mbps; and the IEEE 802.11ac Standard specifies a single-user peak throughput of 6.77 gigabits per second (Gbps). Work has begun on a new standard, IEEE 802.11ax, that promises to provide even greater throughput.

Additionally, work has begun on a two other new standards, IEEE 802.11ah and IEEE 802.11af, each of which will specify wireless network operation in sub-1 GHz frequencies. Low frequency communication channels are generally characterized by better propagation qualities and extended propagation ranges compared to transmission at higher frequencies. In the past, sub-1 GHz ranges have not been utilized for wireless communication networks because such frequencies were reserved for other applications (e.g., licensed TV frequency bands, radio frequency band, etc.). There are few frequency bands in the sub-1 GHz range that remain unlicensed, with different specific unlicensed frequencies in different geographical regions. The IEEE 802.11ah Standard will specify wireless operation in available unlicensed sub-1 GHz frequency bands. The IEEE 802.11af Standard will specify wireless operation in TV White Space (TVWS), i.e., unused TV channels in sub-1 GHz frequency bands.

SUMMARY

In an embodiment, a method for communicating wireless network operational information includes generating, at a communication device, an informational element (IE) to include an indication of a minimum modulation and coding scheme (MCS) allowable in a wireless communication network, wherein the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network, and the indication of the minimum MCS also indicates use of any MCSs below the minimum MCS in the ordered set of MCSs is not allowed in the wireless communication network. The

method also includes generating, at the communication device, a data unit that includes the IE.

In another embodiment, an apparatus comprises a network interface having one or more integrated circuits configured to generate an IE to include an indication of a minimum MCS allowable in a wireless communication network, wherein the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network, and the indication of the minimum MCS also indicates use of any MCSs below the minimum MCS in the ordered set of MCSs is not allowed in the wireless communication network. The one or more integrated circuits are also configured to generate a data unit that includes the IE.

In yet another embodiment, a tangible, non-transitory computer readable medium or media storing machine readable instructions that, when executed by one or more processors, cause the one or more processors to: generate an IE to include an indication of a minimum MCS allowable in a wireless communication network, wherein the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network, and the indication of the minimum MCS also indicates use of any MCSs below the minimum MCS in the ordered set of MCSs is not allowed in the wireless communication network; and generate a data unit that includes the IE.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** a block diagram of an example wireless local area network (WLAN) in which an access point communicates wireless network operational information to stations in the WLAN, according to an embodiment.

FIGS. **2**A and **2**B are diagrams illustrating example placement, within a bandwidth corresponding to a primary channel used in a first mode of operation, of a narrow bandwidth primary channel used in a second mode of operation, according to an embodiment.

FIGS. **3**A-D illustrate an example information element (IE) utilized by an access point to communicate wireless network operational information to stations in a WLAN, according to an embodiment.

FIG. **4** is a flow diagram of an example method for communicating wireless network operational information in a wireless communication network, according to an embodiment.

FIG. **5**A is a diagram of an example media access control (MAC) layer data unit that includes an IE such as the IE of FIGS. **3**A-D, according to an embodiment.

FIG. **5**B is a diagram of an example physical layer (PHY) data unit that includes the MAC layer data unit of FIG. **5**A, according to an embodiment.

DETAILED DESCRIPTION

In embodiments described below, a wireless network device such as an access point (AP) of a wireless local area network (WLAN) transmits data streams to one or more client stations. The AP is configured to operate with client stations according to at least a first communication protocol. In some embodiments, the first communication protocol defines at least two modes of operation including: i) a first mode having a first minimum channel bandwidth, and ii) a second mode having a second minimum channel bandwidth that is a fraction of the first minimum channel bandwidth. As merely an illustrative example, the first minimum channel bandwidth is 2 MHz and the second minimum channel bandwidth is 1 MHz. In other embodiments, other suitable bandwidths and/or fractions are utilized, for example corresponding to first minimum bandwidth and second minimum bandwidth pairs such as 1 MHz/0.5 MHz, 2.5 MHz/1.25 MHz, 3 MHz/1 MHz, 5 MHz/2 MHz, 10 MHz/5 M Hz, etc. In some embodiments, the second mode also is configured to provide longer range operation than the first mode. In other embodiments, however, the first communication protocol does not define different modes with different minimum bandwidths.

In some embodiments, the first communication protocol defines operation in a sub-1 GHz frequency range, and is typically used for applications requiring long range wireless communication with relatively low data rates. In some embodiments, however, the first communication protocol does not defines operation in any sub-1 GHz frequency ranges, and/or is not necessarily used for applications requiring long range wireless communication with relatively low data rates. In some embodiments, the first communication protocol defines operation above 1 GHz. In some embodiments, the first communication protocol is a protocol such as defined by the IEEE 802.11 of Standard or the IEEE 802.11 ah Standard. In other embodiments, the first communication protocol is another suitable wireless communication protocol.

In some embodiments, the AP is also configured to communicate with client stations according to one or more second communication protocols which define operation in generally higher frequency ranges and are typically used for closer-range communications with higher data rates as compared to the first communication protocol. In some embodiments, the one or more second communication protocols are protocols such as defined by the IEEE 802.11a Standard, IEEE 802.11g Standard, the IEEE 802.11n Standard, the IEEE 802.11ac Standard, etc. In other embodiments, however, the one or more second communication protocols are other suitable wireless communication protocols. In some embodiments, the AP is not configured to communicate according to the second communication protocol.

In some embodiments, a first communication device (e.g., an AP or other suitable communication device) is configured to disseminate operational information regarding a wireless communication network (e.g., a WLAN or another suitable wireless communication network) to other second communication devices in the wireless communication network. In various embodiments, the first communication device generates one or more data units that include one or more information elements (IEs). The one or more IEs include the operational information, according to some embodiments.

In various embodiments, the operational information includes one of, or any suitable combination of two or more of: i) a minimum modulation and coding scheme (MCS) that is allowed in the wireless communication network, ii) respective indications of respective minimum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, iii) a position, within a first primary channel for use in the first mode of operation, of a second primary channel for use in the second mode of operation, iv) an indication of whether multiple spatial streams are allowed in the wireless communication network in the second mode of operation, v) an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands, etc.

In some embodiments, the second mode is utilized for various suitable functions. For example, in an illustrative embodiment, the second mode is utilized for sending control-related messages such as beacons, association messages, exchanging of physical layer (PHY) parameters, transmit beamforming training operations, channel estimation operations, etc. In another illustrative embodiment, the second mode is utilized for communicating higher level protocol layer data such as Internet Protocol (IP) layer data, transport control protocol (TCP) layer data, application layer data, etc., over longer ranges than is possible in the first mode.

In some embodiments, the function of the second mode depends on the region in which the second mode is utilized. For example, in one embodiment of an IEEE 802.11ah system in the United States, where a relatively large amount of spectrum is available in sub-1 GHz frequencies, first mode communications utilize channels having a first minimum bandwidth (e.g., 2 MHz, 2.5 MHz, etc.), and the second mode has smaller second minimum bandwidth (e.g., 1 MHz, or 1.25 MHz, etc.). In some embodiments, the AP uses the second mode for signal beacon or association procedures, and/or for transmit beamforming training operations, for example. As another example, in one embodiment of a communication system in which less spectrum is available in sub-1 GHz frequencies (e.g., Europe or Japan), the second mode serves to provide longer ranges as compared to the first mode.

Illustrative examples and embodiments are discussed below in the context of a WLAN. In other embodiments, methods and apparatuses disclosed herein can be utilized with other suitable types of wireless communication networks such as personal area networks (PANs), wide area networks (WANs), metropolitan area networks (MANs), etc.

FIG. **1** is a block diagram of an example WLAN **10** including an AP **14**, according to an embodiment. The AP **14** includes a host processor **15** coupled to a network interface device **16**. The network interface device **16** includes a medium access control (MAC) processing unit **18** and a physical layer (PHY) processing unit **20**. In an embodiment the MAC processing unit **18** is configured to perform MAC layer protocol functions. In an embodiment, the PHY processing unit **20** is configured to perform PHY functions.

The PHY processing unit **20** includes one or more transceivers **21**, and the transceivers **21** are coupled to one or more antennas **24**. Although three transceivers **21** and three antennas **24** are illustrated in FIG. **1**, the AP **14** can include different numbers (e.g., 1, 2, 4, 5, etc.) of transceivers **21** and antennas **24** in other embodiments. The number of antennas **24** need not be the same as the number of transceivers **21**. In some embodiments, multiple transceivers **21** are coupled to the same antenna. In some embodiments, there are more antennas **24** than transceivers **21** and antenna switching techniques are utilized. Additionally, in some embodiments, the network interface **16** is configured to utilize antenna diversity, antenna beamforming, and/or a MIMO technique such as spatial multiplexing.

The WLAN **10** further includes a plurality of client stations **25**. Although four client stations **25** are illustrated in FIG. **1**, the WLAN **10** can include different numbers (e.g., 1, 2, 3, 5, 6, etc.) of client stations **25** in various scenarios and embodiments. At least one of the client stations **25** (e.g., client station **25-1**) is configured to operate at least according to the first communication protocol. In some embodiments, at least one of the client stations **25** (e.g., client station **25-4**) is configured to operate at least according to the second communication protocol. In other embodiments, however, no client stations are configured to operate according to the second communication protocol.

The client station **25-1** includes a host processor **26** coupled to a network interface **27**. The network interface **27** includes a MAC processing unit **28** and a PHY processing unit **29**. In an embodiment the MAC processing unit **28** is configured to perform MAC layer protocol functions. In an embodiment, the PHY processing unit **29** is configured to perform PHY functions.

The PHY processing unit **29** includes a plurality of transceivers **30**, and the transceivers **30** are coupled to a plurality of antennas **34**. Although three transceivers **30** and three antennas **34** are illustrated in FIG. **1**, the client station **25-1** can include different numbers (e.g., 1, 2, 4, 5, etc.) of transceivers **30** and antennas **34** in other embodiments. The number of antennas **34** need not be the same as the number of transceivers **30**. In some embodiments, multiple transceivers **30** are coupled to the same antenna. In some embodiments, there are more antennas **34** than transceivers **30** and antenna switching techniques are utilized. Additionally, in some embodiments, the network interface **27** is configured to utilize antenna diversity, antenna beamforming, and/or a MIMO technique such as spatial multiplexing.

In some embodiments, one, some, or all of the client stations **25-2**, **25-3**, and **25-4** has/have a structure the same as or similar to the client station **25-1**. In these embodiments, the client stations **25** structured the same as or similar to the client station **25-1** have the same or a different number of transceivers and antennas. For example, the client station **25-2** has only two transceivers and two antennas, according to an embodiment.

In various embodiments, the PHY processing unit **20** of the AP **14** is configured to generate data units conforming to the first communication protocol and having formats described hereinafter. The transceiver(s) **21** is/are configured to transmit the generated data units via the antenna(s) **24**. Similarly, the transceiver(s) **21** is/are configured to receive data units via the antenna(s) **24**. The PHY processing unit **20** of the AP **14** is also configured to process received data units conforming to the first communication protocol and having formats described hereinafter, according to various embodiments.

In various embodiments, the PHY processing unit **29** of the client device **25-1** is configured to generate data units conforming to the first communication protocol and having formats described hereinafter. The transceiver(s) **30** is/are configured to transmit the generated data units via the antenna(s) **34**. Similarly, the transceiver(s) **30** is/are configured to receive data units via the antenna(s) **34**. The PHY processing unit **29** of the client device **25-1** is also configured to process received data units conforming to the first communication protocol and having formats described hereinafter, according to various embodiments.

In some embodiments, the AP **14** is configured to operate in dual frequency band configurations. In such embodiments, the AP **14** is able to switch between using the first communication protocol and the second communication protocol. Similarly, the client station **25-1** is capable of dual frequency band operation, according to some embodiments. In these embodiments, the client station **25-1** is able to switch between using the first communication protocol and the second communication protocol. In other embodiments, the AP **14** and/or the client station **25-1** is a single band device configured to utilize only the first communication protocol.

In some embodiments, the first communication protocol defines a plurality of MCSs for use in wireless communication networks. In some embodiments, each MCS provides a different data rate for a given set of one or more other parameters, e.g., length of guard interval utilized, number of spatial streams utilized, etc. Thus, in some embodiments, the MCSs can be ordered based on throughput to provide an ordered set of MCSs. In some embodiments, as MCSs decrease in the order, robustness increases (e.g., a lower MCS provides better performance in the presence of noise, interference, etc., as compared to a higher MCS). In some embodiments, as MCSs decrease in the order, range increases (e.g., a lower MCS provides a longer range as compared to a higher MCS). Thus, in some embodiments, the MCSs can be ordered based on, for example, robustness, range, etc.

In some embodiments, the AP **14** is configured to set a minimum MCS for the WLAN **10** such that any MCSs below the minimum MCS in the ordered set of MCSs are not allowed in the WLAN **10**. Additionally, the AP **14** is configured to transmit an indication of the minimum MCS for the WLAN **10** to the stations **25**. In some embodiments, the AP **14** is configured to set respective minimum MCSs for the WLAN **10** for different numbers of spatial streams. Additionally, the AP **14** is configured to transmit respective indications of the minimum MCSs for different numbers of spatial streams for the WLAN **10** to the stations **25**. In some embodiments, the AP **14** is configured to generate an information element (IE) that includes operational information comprising the indication(s) of the minimum MCS(s). In some embodiments, the AP **14** is configured to generate a data unit (e.g., a MAC layer data unit, a PHY data unit, etc.) that includes the IE. In various embodiments, the data unit is a beacon data unit, an association response data unit, a probe response data unit, etc.

Upon receiving the indication(s) of the minimum MCS(s), the stations **25** refrain from using any MCSs below the indicated minimum MCS(s) (at least for the certain numbers of spatial streams, in some embodiments), according to an embodiment. In some embodiments in which different MCSs provide different ranges, setting the minimum MCS(s) above an absolute minimum MCS defined by the first communication protocol has an effect of reducing the range of the network **10** as compared to the network **10** using MCSs below the indicated minimum MCS(s). By reducing the range of networks in this manner, more networks can be located within a given spatial (e.g., geographic) area, at least in some embodiments.

In some embodiments in which a first mode and a second mode are utilized such as described above, the AP **14** is configured to set a location (in frequency) of a narrower primary channel for the second mode of operation within a primary channel for the first mode of operation. FIG. **2**A is a diagram of an illustrative example of a composite channel **200** that is utilized in the network **10**, according to an illustrative embodiment. The composite channel **200** is utilized in the first mode in which a smallest channel unit of width is 2 MHz (as merely an illustrative example). The composite channel **200** includes a primary channel **204** and a secondary channel **208**.

A primary channel **212** is utilized in the second mode of operation in which the smallest channel unit of width is 1 MHz (as merely an illustrative example). In the example of FIG. **2**A, the primary channel **212** is located in a lower half of the bandwidth of the primary channel **204**. On the other hand, in the example of FIG. **2**B, the primary channel **212** is located in an upper half of the bandwidth of the primary channel **204**.

Thus, in some embodiments, the AP **14** is configured to transmit an indication of the location (in frequency) of the primary channel **212** within the bandwidth corresponding to the primary channel **204** for the WLAN **10** to the stations **25**. In some embodiments, the AP **14** is configured to generate an IE that includes operational information comprising the indication of the location of the primary channel **212** within the bandwidth corresponding to the primary channel **204**. In some embodiments, the IE that includes the indication of the location of the primary channel **212** within the bandwidth corresponding to the primary channel **204** also includes the indication(s) of the minimum MCS(s), as discussed above. In some embodiments, the AP **14** is configured to generate a data unit (e.g., a MAC layer data unit, a PHY data unit, etc.) that includes the IE. In various embodiments, the data unit is, or includes, a beacon data unit, an association response data unit, a probe response data unit, etc.

Upon receiving the indication of the location of the primary channel **212** within the bandwidth corresponding to the primary channel **204**, the network interfaces **27** of the stations **25** configure themselves to utilize the appropriate primary channel **212** when operating the second mode, according to an embodiment. In some embodiments, this technique facilitates permitting different locations of the primary channel **212** within the bandwidth of the primary channel **204**. This may help to reduce interference with another WLAN that is proximate to the WLAN **10**, at least in some embodiments. For example, in some embodiments, when the other WLAN is also using bandwidth corresponding to the primary channel **204** as its primary channel and is capable of operating in the second mode, the AP **14** can determine bandwidth within the primary channel **204** that the other WLAN is using for its second mode primary channel, and then select a location of the primary channel **212** that is different than that used by the other WLAN. As another example, in some embodiments, when the other WLAN is also using bandwidth corresponding to the primary channel **204** as its primary channel and is capable of operating in the second mode, the AP **14** can determine bandwidth within the primary channel **204** that the other WLAN is using for its second mode primary channel, and then select a location of the primary channel **212** that is the same as that used by the other WLAN.

Although FIGS. **2**A and **2**B were discussed with respect to specific bandwidths of the primary channel **204** and the primary channel **212**, other suitable bandwidths are utilized in other embodiments. Additionally, although FIGS. **2**A and **2**B were discussed with respect to the bandwidth of the primary channel **212** being one half the bandwidth of the primary channel **204**, the bandwidth of the primary channel **212** is another suitable fraction (e.g., one third, one quarter, one fifth, etc.) of the bandwidth of the primary channel **204**, in other embodiments. Thus, in some embodiments, there are more than two possible locations of the primary channel **212** within the bandwidth of the primary channel **204** (e.g., three locations (e.g., upper third, middle third, lower third), four locations, five locations, etc.).

In some embodiments, the AP **14** is configured to set an operating class of the WLAN **10**, where the operating class corresponds to a particular frequency spectrum. In some embodiments, the operating class is indicated by a starting frequency, and a channel spacing. In some embodiments, the operating class also corresponds to a set of channels. In other embodiments, the operating class is indicated additionally or alternatively using other suitable parameters such as i) a starting frequency and an ending frequency, ii) a starting frequency and a bandwidth, etc. In some embodiments, the AP **14** is configured to generate an IE that includes operational information comprising an indication of the operating class. In some embodiments, the IE that includes the indication of the operating class also includes one or both of i) the indication(s) of the minimum MCS(s) (as discussed above), and/or ii) the location of the primary channel **212** within the bandwidth corresponding to the primary channel **204** also includes the indication(s) of the minimum MCS(s) (as discussed above). In some embodiments, the AP **14** is configured to generate a data unit (e.g., a MAC layer data unit, a PHY data unit, etc.) that includes the IE. In various embodiments, the data unit is, or includes, a beacon data unit, an association response data unit, a probe response data unit, etc.

Upon receiving the indication of the operating class, the network interfaces **27** of the stations **25** configure themselves to operate in the operating class, according to an embodiment. In some embodiments, the indication of the operating class includes a starting frequency and a channel spacing. In some embodiments, the indication of the operating class also includes an indication of a set of channels. In other embodiments, the indication of the operating class additionally or alternatively includes other suitable parameters such as i) a starting frequency and an ending frequency, ii) a starting frequency and a bandwidth, etc.

In some embodiments, the AP **14** is configured to set whether more than one spatial stream can be utilized in the WLAN **10** in the second mode. In some embodiments, the AP **14** is configured to generate an IE that includes operational information comprising an indication of whether more than one spatial stream can be utilized in the WLAN **10** in the second mode. In some embodiments, the IE that includes the indication of whether more than one spatial stream can be utilized in the WLAN **10** in the second mode, also includes any one of, any two of, or all of i) the indication(s) of the minimum MCS(s) (as discussed above), ii) the location of the primary channel **212** within the bandwidth corresponding to the primary channel **204** also includes the indication(s) of the minimum MCS(s) (as discussed above), and/or iii) the indication of the operating class. In some embodiments, the AP **14** is configured to generate a data unit (e.g., a MAC layer data unit, a PHY data unit, etc.) that includes the IE. In various embodiments, the data unit is, or includes, a beacon data unit, an association response data unit, a probe response data unit, etc.

Upon receiving the indication that more than one spatial stream cannot be utilized in the WLAN **10** in the second mode, the network interfaces **27** of the stations **25** configure themselves to not use more than one spatial stream in the WLAN **10** in the second mode.

FIGS. **3**A-D are diagrams of an example IE **300** that includes operational information such as described above, according to an illustrative embodiment. In other embodiments, one or more other suitable IEs are utilized.

Referring now to FIG. **3**A, the IE **300** includes an element identifier **304**, a length field **308** to indicate a length of the IE **300**, a sub-1 Gigahertz (S1G) operational information field **312**, and a basic S1G-MCS and Nss Set field **316**. Example lengths of fields of the IE **300** are illustrated in FIG. **3**A. In other embodiments, other suitable lengths are utilized. The fields **312** and **316** are described in more detail with reference to FIGS. **3**B-D.

For example, FIG. **3**B illustrates the field **312**, according to an illustrative embodiment, in more detail. The field **312** includes three subfields **320**, **324**, and **328**. The subfield **320** provides information regarding the width of a channel that is to be utilized in the WLAN **10**. For example, if channel bonding is utilized, multiple unit channels can be utilized to form a composite channel having a bandwidth equal to an integer multiple of a unit channel bandwidth, in some embodiments. The subfield **320** also provides information regarding position of a primary channel utilized in the second mode within a bandwidth corresponding to a primary channel utilized in the first mode, as discussed above. The subfield **320** also provides an indication of whether multiple spatial streams can be utilized when operating in the second mode. The subfield **320** is described in more detail with reference to FIG. **3**C.

The subfield **324** provides an indication of an operating class utilized by the WLAN **10**. The subfield **328** provides an indication of the primary channel utilized by the WLAN **10** in the first mode.

FIG. **3**C is a table **340** describing the field **312** in more detail, according to an illustrative embodiment. For example, bits B**0**-B**2** of subfield **320** are utilized to indicate whether the channel to be utilized has a bandwidth of 1 MHz, 2 MHz, 4 MHz, 8 MHz, or 16 MHz. Bit B**3** of subfield **320** is utilized to indicate a position of the primary channel in the second mode within the bandwidth of the primary channel of the first mode. Bits B**4**-B**6** of subfield **320** are utilized to indicate a position of the primary channel in the first mode within the bandwidth of the overall channel.

The subfield **324** is encoded in a suitable manner to indicate the operating class. In some embodiments, the subfield **324** is encoded to indicate a starting frequency and a channel spacing corresponding to an operating class. In some embodiments, the subfield **324** is encoded to also indicate a set of channels corresponding to the operating class. In other embodiments, the subfield **324** is encoded to additionally or alternatively indicate other suitable parameters such as i) a starting frequency and an ending frequency, ii) a starting frequency and a bandwidth, etc.

The subfield **328** is encoded in a suitable manner to indicate a channel number corresponding to the primary channel in the first mode. For example, the subfield **328** is encoded to indicate a channel identifier such as a channel number or other suitable identifier, according to some embodiments. [

Referring now to FIG. **3**D, an example embodiment of the field **316** of the IE **300** is illustrated. The field **316** includes four subfields that indicate a respective minimum MCS for when one spatial stream is utilize, when two spatial streams are utilized, when three spatial streams are utilized, and when four spatial streams are utilized. Similarly, in an embodiment, the field **316** includes four subfields that indicate a respective maximum MCS for when one spatial stream is utilized, when two spatial streams are utilized, when three spatial streams are utilized, and when four spatial streams are utilized.

FIG. **4** is a flow diagram of an example method **400** for communicating wireless network operational information in a wireless communication network, according to an embodiment. In an embodiment, the method **400** is implemented by an AP in the WLAN, according to an embodiment. With reference to FIG. **1**, the method **400** is implemented by the AP **14**. For example, the method **400** is implemented by the MAC processing unit **18**, by the PHY processing unit **20** of the AP **14**, and/or by the host processor **15**, according to various embodiments. In other embodiments, the method **400** is implemented by other components of the AP **14**, or is implemented by a suitable communication device other than the AP **14**.

At block **404**, an IE is generated to include one of or any suitable combination of two or more of: i) an indication of a minimum MCS allowable in the wireless communication network, ii) an indication of a position of a primary channel for the second mode within a bandwidth corresponding to a primary channel for the first mode of operation, iii) an indication of whether multiple spatial streams are allowed in the wireless communication network when operating in the second mode, and/or iv) an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands.

If block **404** includes generating the IE to include the indication of the minimum MCS, the method also includes setting the minimum MCS, according to an embodiment. If block **404** includes generating the IE to include the indication of the position of the primary channel for the second mode within the bandwidth corresponding to the primary channel for the first mode of operation, the method also includes setting the position, according to an embodiment. If block **404** includes generating the IE to include the indication of whether multiple spatial streams are allowed in the wireless communication network when operating in the second mode, the method also includes setting whether multiple spatial streams are allowed in the wireless communication network when operating in the second mode, according to an embodiment. If block **404** includes generating the IE to include the indication of the operating class, the method also includes setting the operating class, according to an embodiment.

At block **408**, a data unit is generated to include the IE. In an embodiment, block **408** includes generating a MAC layer data unit that includes the IE. For example, in an embodiment, the MAC layer data unit is generated to include the IE in a payload of the MAC layer data unit. Referring now to FIG. **5**A, a MAC layer data unit **500** includes a payload **504** having an IE **508** generated according to block **404** of FIG. **4**. Referring again to FIG. **4**, in an embodiment, block **408** includes generating a PHY data unit that includes the IE. For example, in an embodiment, the PHY data unit is generated to include the MAC layer data unit discussed above, which includes the IE. Referring now to FIG. **5**B, a PHY data unit **550** includes the MAC layer data unit **500** of FIG. **5**A.

Referring again to FIG. **4**, in some embodiments, the method further includes transmitting the data unit generated at block **408**. In some embodiments, method further includes initiating transmission of the data unit generated at block **408**.

At least some of the various blocks, operations, and techniques described above may be implemented utilizing hardware, a processor executing firmware instructions, a processor executing software instructions, or any combination thereof. When implemented utilizing a processor executing software or firmware instructions, the software or firmware instructions may be stored in any non-transient, tangible computer readable medium or media such as a magnetic disk, an optical disk, a random access memory (RAM), a read-only memory (ROM), a flash memory, a magnetic tape, etc. The software or firmware instructions may include machine readable instructions that, when executed by one or more processors, cause the one or more processors to perform various acts.

When implemented in hardware, the hardware may comprise one or more of discrete components, an integrated circuit, an application-specific integrated circuit (ASIC), a programmable logic device (PLD), etc.

While the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, changes, additions and/or deletions may be made to the disclosed embodiments without departing from the scope of the invention.

What is claimed is:

1. A method for communicating wireless network operational information, the method comprising:

generating, at a first communication device, an informational element (IE) to include an indication of a minimum modulation and coding scheme (MCS) allowable in a wireless communication network, wherein

the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network; and

generating, at the communication device, a physical layer (PHY) protocol data unit that includes the IE, the PHY protocol data unit for transmission in the wireless communication network to one or more second communication devices, such that when the one or more second communication devices receive the PHY protocol data unit having the indication of the minimum MCS, the one or more second communication devices refrain from using any MCSs below the minimum MCS in the ordered set of MCSs.

2. The method of claim 1, wherein generating the IE includes generating the IE to include respective indications of respective minimum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each minimum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective minimum MCSs, the one or more second communication devices refrain from using any MCSs below the respective minimum MCS in the ordered set of MCSs when using the respective number of spatial streams.

3. The method of claim 2, wherein generating the IE includes generating the IE to include respective indications of respective maximum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each maximum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective maximum MCSs, the one or more second communication devices refrain from using any MCSs above the respective maximum MCS in the ordered set of MCSs when using the respective number of spatial streams.

4. The method of claim 1, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

generating the IE includes generating the IE to include an indication of a position of the second primary channel within the primary channel for the second mode of operation.

5. The method of claim 1, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

generating the IE includes generating the IE to include an indication of whether multiple spatial streams are allowed in the wireless communication network when using the second primary channel in the second mode of operation.

6. The method of claim 1, wherein generating the IE includes generating the IE to include an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands.

7. An apparatus, comprising:

a network interface of a first communication device, the network interface having one or more integrated circuits, the network interface comprising:

a media access control (MAC) processing unit implemented on the one or more integrated circuits, the MAC processing unit configured to

generate an informational element (IE) to include an indication of a minimum modulation and coding scheme (MCS) allowable in a wireless communication network, wherein

the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network, and

generate a MAC layer protocol data unit that includes the IE;

wherein the network interface further comprises:

a physical layer (PHY) processing unit coupled to the MAC processing unit, the PHY processing unit implemented on the one or more integrated circuits, the PHY processing unit being configured to generate a PHY protocol data unit that includes the MAC layer protocol data unit, the PHY protocol data unit for transmission in the wireless communication network to one or more second communication devices, such that when the one or more second communication devices receive the PHY protocol data unit having the indication of the minimum MCS, the one or more second communication devices refrain from using any MCSs below the minimum MCS in the ordered set of MCSs.

8. The apparatus of claim 7, wherein the MAC processing unit is configured to generate the IE to include respective indications of respective minimum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each minimum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective minimum MCSs, the one or more second communication devices refrain from using any MCSs below the respective minimum MCS in the ordered set of MCSs when using the respective number of spatial streams.

9. The apparatus of claim 8, wherein the MAC processing unit is configured to generate the IE to include respective indications of respective maximum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each maximum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective maximum MCSs, the one or more second communication devices refrain from using any MCSs above the respective maximum MCS in the ordered set of MCSs when using the respective number of spatial streams.

10. The apparatus of claim **7**, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

the MAC processing unit is configured to generate the IE to include an indication of a position of the second primary channel within the first primary channel for the second mode of operation.

11. The apparatus of claim **7**, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

the MAC processing unit is configured to generate the IE to include an indication of whether multiple spatial streams are allowed in the wireless communication network when using the second primary channel in the second mode of operation.

12. The apparatus of claim **7**, wherein the MAC processing unit is configured to generate the IE to include an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands.

13. A tangible, non-transitory computer readable medium, or media, storing machine readable instructions that, when executed by one or more processors of a first communication device, cause the one or more processors to:

generate an informational element (IE) to include an indication of a minimum modulation and coding scheme (MCS) allowable in a wireless communication network, wherein

the minimum MCS is from an ordered set of multiple MCSs defined by a communication protocol utilized by the wireless communication network; and

generate a media access control (MAC) protocol layer data unit that includes the IE, the MAC layer protocol data unit for inclusion in a physical layer (PHY) protocol data unit for transmission in the wireless communication network to one or more second communication devices, such that when the one or more second communication devices receive the PHY protocol data unit having the indication of the minimum MCS, the one or more second communication devices refrain from using any MCSs below the minimum MCS in the ordered set of MCSs.

14. The tangible, non-transitory computer readable medium, or media, of claim **13**, further storing machine readable instructions that, when executed by the one or more processors, cause the one or more processors to:

generate the IE to include respective indications of respective minimum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each minimum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective minimum MCSs, the one or more second communication devices refrain from using any MCSs below the respective minimum MCS in the ordered set of MCSs when using the respective number of spatial streams.

15. The tangible, non-transitory computer readable medium, or media, of claim **14**, further storing machine readable instructions that, when executed by the one or more processors, cause the one or more processors to:

generate the IE to include respective indications of respective maximum MCSs allowable in the wireless communication network for corresponding different numbers of spatial streams, wherein:

each maximum MCS is from the ordered set of multiple MCSs defined by the communication protocol, such that when the one or more second communication devices receive the PHY protocol data unit having the respective indications of respective maximum MCSs, the one or more second communication devices refrain from using any MCSs above the respective maximum MCS in the ordered set of MCSs when using the respective number of spatial streams.

16. The tangible, non-transitory computer readable medium, or media, of claim **13**, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

the computer readable medium or media further stores machine readable instructions that, when executed by the one or more processors, cause the one or more processors to generate the IE to include an indication of a position of the second primary channel within the first primary channel for the second mode of operation.

17. The tangible, non-transitory computer readable medium, or media, of claim **13**, wherein:

the communication protocol defines i) a first mode of operation in which a first primary channel utilized by the wireless communication network has a first bandwidth, and ii) a second mode of operation in which a second primary channel utilized by the wireless communication network has a second bandwidth that is a fraction of the first bandwidth; and

the computer readable medium or media further stores machine readable instructions that, when executed by the one or more processors, cause the one or more processors to generate the IE to include an indication of whether multiple spatial streams are allowed in the wireless communication network when using the second primary channel in the second mode of operation.

18. The tangible, non-transitory computer readable medium, or media, of claim **13**, further storing machine readable instructions that, when executed by the one or more processors, cause the one or more processors to generate the IE to include an indication of an operating class from a plurality of operating classes corresponding to respective frequency bands.

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